

## Appendix 2.1 IPCC 4<sup>th</sup> Assessment Climate Projections

These robust conclusions, which we believe also apply to the climate projections from the SAP 2.1a scenarios, are taken primarily from the Executive Summary of Chapter 10 of the IPCC's 4<sup>th</sup> Assessment Report (IPCC, 2007a) as well as some details extracted from the body of Chapter 10, and are summarized below.

### A.2.1.1 Mean Temperature

All AOGCMs In Chapter 10 of the AR4 (IPCC, 2007a) project increases in global mean surface air temperature (SAT) throughout the 21<sup>st</sup> century, with the warming proportional to the associated radiative forcing. There is close agreement among globally averaged SAT multi-model mean warming for the early 21<sup>st</sup> century for the three SRES (B1, A1B and A2) scenarios as well as for SAP 2.1a Level 2-4 scenarios out to 2050. The warming rate over the next few decades in Chapter 10 (IPCC, 2007a) is affected little by different scenario assumptions or different model sensitivities, and is similar to that observed for the past few decades. By mid-century (2046 – 2065), the choice of SRES scenario becomes more important and they start to separate, though the range among the collection of AOGCMs is comparable. By the end of the 21<sup>st</sup> century, the SATs generated by MAGICC using the 12 SAP 2.1 scenarios as well as the full spread of all of the AOGCMs for the A2, B1 and Committed projections have completely separated, though A1B still has some overlap with A2 and B1.

In general, geographical patterns of projected SAT warming show greatest temperature increases over land (roughly twice the global average temperature increase) and at high northern latitudes, and show less warming over the southern oceans and North Atlantic, consistent with observations during the latter part of the 20th century. These patterns are similar across the B1, A1B, and A2 scenarios (see Figure 10.8 in Chapter 10 of the AR4; IPCC, 2007a) only increasing in magnitude with increasing radiative forcing. Results for the stabilization scenarios similar to those studied here should show the same pattern similarities at least out to 2100 (see, *e.g.*, Dai *et al.* 2001a, b). It should be noted that, in none of the cases considered here, has the climate stabilized by 2100 – for the higher stabilization levels this may take centuries. Temperature change patterns may differ as one approaches closer to a stable climate.

#### **A.2.1.2 Temperature Extremes**

It is very likely that heat waves will be more intense, more frequent and longer lasting in a future warmer climate. Cold episodes are projected to decrease significantly in a future warmer climate. Almost everywhere, daily minimum temperatures are projected to increase faster than daily maximum temperatures, leading to a decrease in diurnal temperature range. Decreases in frost days are projected to occur almost everywhere in the mid and high latitudes, with a comparable increase in growing season length (IPCC, 2007a).

**A.2.1.3 Mean Precipitation**

Globally averaged mean atmospheric water vapor, evaporation and precipitation are projected to increase. By 2100, precipitation generally increases in the areas of regional tropical precipitation maxima (such as the monsoon regimes) and over the tropical Pacific in particular, with general decreases in the subtropics, and increases at high latitudes as a consequence of a general intensification of the global hydrological cycle. The geographical patterns of precipitation change during the 21<sup>st</sup> century are not as consistent across AOGCMs and across scenarios as they are for surface temperature (IPCC, 2007a).

**A.2.1.4 Precipitation Extremes and Droughts**

Intensity of precipitation events is projected to increase, particularly in tropical and high latitude areas that experience increases in mean precipitation. There is a tendency for drying of the mid-continental areas during summer, indicating a greater risk of droughts in those regions. Precipitation extremes increase more than the mean in most tropical and mid- and high latitude areas (IPCC, 2007a).

**A.2.1.5 Snow and Ice**

As the climate warms, snow cover and sea ice extent decrease; glaciers and ice caps lose mass owing to dominance of summer melting over winter precipitation increases. There is a projected reduction of sea ice in the 21st century both in the Arctic and Antarctic with a large range of model responses. Widespread increases in thaw depth over much of the permafrost regions are projected to occur in response to warming over the next century (IPCC, 2007a).

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1441 **Note:** All of the AR4 predictions for precipitations, snow cover and sea and land ice are  
1442 less certain and more variable across the suite of AOGCMs than they are for both the  
1443 global average and the more robust geographic patterns of temperature.

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#### 1445 **A.2.1.6 Carbon Cycle**

1446 Under the SRES illustrative emissions scenarios, for central carbon-cycle model  
1447 parameters, CO<sub>2</sub> concentrations are projected to increase from its present value of about  
1448 380 ppm to 540–970 ppm by 2100. The SAP 2.1a Reference scenarios give 2100  
1449 concentrations of 740–850 ppm. There is unanimous agreement amongst the simplified  
1450 climate-carbon cycle models that future climate change would reduce the efficiency of  
1451 the Earth system (land and ocean) to absorb anthropogenic carbon dioxide. The higher  
1452 the stabilization scenario warming, the larger is the impact on the carbon cycle. Both  
1453 MAGICC and two of the three integrated assessment models used in SAP 2.1a contain  
1454 simplified carbon cycle models comparable to those in Chapter 10 of the AR4 (IPCC,  
1455 2007a).

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#### 1457 **A.2.1.7 Ocean Acidification**

1458 Increasing atmospheric CO<sub>2</sub> concentrations lead directly to increasing acidification of the  
1459 surface ocean. Multi-model projections based on SRES scenarios give reductions in pH  
1460 of between 0.14 and 0.35 units over the 21st century, adding to the present decrease of  
1461 0.1 units from pre-industrial times. Southern Ocean surface waters are projected to  
1462 exhibit undersaturation with regard to CaCO<sub>3</sub> for CO<sub>2</sub> atmospheric concentrations higher

than 600 ppm. Low latitude regions and the deep ocean will be affected as well. While ocean acidification would lead to dissolution of shallow-water carbonate sediments and could affect marine calcifying organisms, the net effect on the biological cycling of carbon in the oceans is not well understood (IPCC, 2007a).

#### **A.2.1.8 Sea Level**

“Sea level is projected to rise between the present (1980-1999) and the end of this century (2090-2099) under the SRES B1 scenario by 0.28 m for the multi-mode average (range 0.19 to 0.37 m), under A1B by 0.35 m (0.23 to 0.47 m), under A2 by 0.37 m (0.25 to 0.50 m) and under A1FI by 0.43 m (0.28 to 0.58 m). These are central estimates with 5-95% intervals based on AOGCM results, not including uncertainty in carbon-cycle feedbacks. In all scenarios, the average rate of rise during the 21st century very likely exceeds the 1961–2003 average rate ( $1.8 \pm 0.5 \text{ mm yr}^{-1}$ ). During 2090 – 2099 under A1B, the central estimate of the rate of rise is  $3.8 \text{ mm yr}^{-1}$ . For an average model, the scenario spread in sea level rise is only 0.02 m by the middle of the century, and by the end of the century it is 0.15 m.”(IPCC, 2007a) The projections of sea-level rise for the 12 SAP 2.1 scenarios by MAGICC are within the range reported by AR4 (Wigley *et al.*, 2007b).

“Thermal expansion is the largest component, contributing 60-70% of the central estimate in these projections for all scenarios. Glaciers, ice caps and the Greenland ice sheet are also projected to contribute positively to sea level. GCMs indicate that the Antarctic ice sheet will receive increased snowfall without experiencing substantial

surface melting, thus gaining mass and contributing negatively to sea level. Further accelerations in ice flow of the kind recently observed in some Greenland outlet glaciers and West Antarctic ice streams could substantially increase the contribution from the ice sheets. Current understanding of these effects is limited, so quantitative projections cannot be made with confidence” (IPCC, 2007a).

#### **A.2.1.9 Ocean Circulation**

- a. There is no consistent change in the ENSO for those AOGCMs with a quasi-realistic base state.
- b. Among those models with a realistic Atlantic Meridional Overturning Circulation (MOC), while it is very likely that the MOC will slow by 2100, there is little agreement among models for the magnitude of the slow-down. Models agree that the MOC will not shut down completely (IPCC, 2007a).

#### **A.2.1.10 Monsoons**

Current AOGCMs predict that, in a warmer climate, there will be an increase in precipitation in both the Asian monsoon (along with an increase in interannual variability) and the southern part of the west African monsoon with some decrease in the Sahel in northern summer, as well as an increase in the Australian monsoon in southern summer. The monsoonal precipitation in Mexico and Central America is projected to decrease in association with increasing precipitation over the eastern equatorial Pacific. However, the uncertain role of aerosols complicates the projections of monsoon precipitation, particularly in the Asian monsoon (IPCC, 2007a).

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1510 **A.2.1.11 Tropical Cyclones (Hurricanes and Typhoons)**

1511 The Summary for Policymakers finds it **likely** that intense hurricanes and typhoons will  
1512 increase through the 21<sup>st</sup> century as it warms. Results from embedded high-resolution  
1513 models and global models, ranging in grid spacing from 1 degree to 9 km, generally  
1514 project increased peak wind intensities and notably, where analyzed, increased near-  
1515 storm precipitation in future tropical cyclones (IPCC, 2007a). However, these questions  
1516 of changes in frequency and intensity under global warming continue to be the subject of  
1517 very active research.

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1519 **A.2.1.12 Midlatitude Storms**

1520 Model projections show fewer midlatitude storms averaged over each hemisphere,  
1521 associated with the poleward shift of the storm tracks that is particularly notable in the  
1522 Southern Hemisphere, with lower central pressures for these poleward-shifted storms.  
1523 The increased wind speeds result in more extreme wave heights in those regions (IPCC,  
1524 2007a).

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1526 **A.2.1.13 Radiative Forcing**

1527 “The radiative forcings by long-lived greenhouse gases computed with the radiative  
1528 transfer codes in twenty of the AOGCMs used in the AR4 have been compared against  
1529 results from benchmark line-by-line (LBL) models. The mean AOGCM forcing over the  
1530 period 1860 to 2000 agrees with the mean LBL value to within  $0.1 \text{ W m}^{-2}$  at the  
1531 tropopause. However, there is a range of 25% in longwave forcing due to doubling  $\text{CO}_2$

from its concentration in 1860 across the ensemble of AOGCM codes. There is a 47% relative range in longwave forcing at 2100 contributed by all greenhouse gases in the A1B scenario across the ensemble of AOGCM simulations. These results imply that the ranges in climate sensitivity and climate response from models discussed in this chapter may be due in part to differences in the formulation and treatment of radiative processes among the AOGCMs.”(IPCC, 2007a)

#### **A.2.1.14 Climate Change Commitment (Temperature and Sea Level)**

“Results from the AOGCM multi-model climate change commitment experiments (concentrations stabilized for 100 years at year 2000 for 20th century commitment, and at 2100 values for B1 and A1B commitment) indicate that if greenhouse gases were stabilized, then a further warming of 0.5°C would occur.”(IPCC, 2007a)

“If concentrations were stabilized at A1B levels in 2100, sea level rise due to thermal expansion in the 22nd century would be similar to in the 21st, and would amount to 0.3–0.8 m above present by 2300. The ranges of thermal expansion overlap substantially for stabilization at different levels, since model uncertainty is dominant; A1B is given here because most model results are available for that scenario. Thermal expansion would continue over many centuries at a gradually decreasing rate, reaching an eventual level of 0.2–0.6 m per degree of global warming relative to present.”(IPCC, 2007a)